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Study on Early warning model of Coal mining engineering with Fuzzy AHP

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Abstract

The safety issue of coal mining engineering is very important to coal industry. According to our coal mine enterprises' safe characteristics, this paper analyzed the risk factors of coal mining engineering and studied the safety problem of “human-machine-environment” system. The risk factors of coal mining engineering are divided to natural geological factors, personnel factors, equipment factors and management factors. Based on the fuzzy mathematics and these factors, the safety early warning model of coal mining engineering is constructed by using the fuzzy AHP method. Through the use of early warning model, we can find the risk sources and hidden danger of mining operations in time. Combined with a production mine, this early warning model is applied to the mining operations process. The results show that this early warning model is effective to prevent the accident.

Keywords: coal mining engineering; safety early warning; Analytic Hierarchy Process; fuzzy mathematics

1. Introduction

Coal mine safety management is very important to coal mining engineering. Many research works about coal mine safety management are done by Chinese scholars and the coal mine safety management has been greatly improved in recent years. But according to the overall development level of coal industry, the Chinese coal mine enterprise management is in the empirical accident management stage and can't meet the practical needs by enterprise production actions. It is an urgent task to break island state of security information and excavate the valuable information from the feedback data of coal mining system[1]. Based on the fuzzy mathematics, this paper constructs a safety early warning model of coal mining engineering. Combining safety factors of coal mine, the safety early warning model can be used to improve safety management situation of coal mine enterprises.

The research object of safety early warning is “human-machine-environment” system. By using modern tools and technology, we can get all kinds of safety related data and carry out a series of activities such as assessment, review, classification, analysis and monitoring, etc. Then the security warning signals in different stages can be got[2]. Base on the risk signals are conveyed in time, we can get the safety data about coal mining engineering with the safety early warning model. By contrast wit the risk management threshold, we can adopt different control behaviors to avoid accidents.

The main activities of safety early warning about coal mining engineering include monitoring and identification of hazards, alert diagnosis and evaluation, warning decision, anticipating control and control, trend forecast and so

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on. These activities can be divided into warning analysis and warning countermeasures. At first, by monitoring the hazards of production process, signals are collected from the external environment and each subsystem according to the monitoring indexes system. Through the analysis of the monitoring information, alert is identified. It means that we use appropriate identification index to estimate the alert that has happened and will happen. To the alert happened we can make the diagnosis and evaluation and forecast the development trend and harm degree. Then the corresponding control measures can be adopted[3].

2. The safety early warning model of coal mining engineering

The safety early warning model of coal mining engineering includes many indexes. And each index includes lots of related factors. To these factors, some can be quantitative expression and some can only be qualitative expression. So we can combine Analytic Hierarchy Process (AHP) with fuzzy comprehensive evaluation approach to get the safety early warning model of coal mining engineering. The multi-grade fuzzy comprehensive evaluation about quantitative index together with qualitative index can be achieved.

The Analytic Hierarchy Process (AHP) is a structured technique for helping people deal with complex decisions. The AHP can help we deal with qualitative problems with quantitative analysis method.

① Each index in system should be resolved into several levels. Every index at the same level is subject to the upper index and governs the lower index. Then a hierarchical structure model about the problem can be constructed.

② The relationship of indexes in system should be analyzed. With a rule, one index should be compared with another index at the same level about the importance to the upper index. Then a comparison matrix about the comparison process can be got.

③ The weight of every index can be got with the comparison matrix based on the rule and the consistency of comparison matrix should be tested. Then with weight of indexes, the total arrangement weight of the level to system can be got.

2.1. The evaluation grade set of safety early warning model

The evaluation grade set of safety early warning model is a qualitative description about safe state of indexes. The safety class Is divided into 5 grades in this paper and the evaluation grade set is V= $\{v_1, v_2, v_3, v_4, v_5\}$ = {very safe, safe, common, risky, very risky}.

2.2. The warning monitoring index set of safety early warning model

Combined with security theory of coal mining engineering and actual situation of the coal mine, the warning monitoring indexes system consists of geological environment, human, equipment, working condition, management. Each warning monitoring index consists of some junior index[4]. For example, the environmental monitoring index is composed of average wind speed, the supply-demand ratio of air flow, the minimum pedestrian elevation of mine workings, the minimum pedestrian width of mine workings, temperature, dust concentration, the qualification rate of mine workings. Based on the warning monitoring indexes system, the warning monitoring index set is U= $(U_1, U_2, U_3, U_4, U_5)$ that is corresponding to geological environment, human, equipment, working condition, management. The index U_i is composed of the lower index that is mean $U_i = \{U_{ij}\}$, j=1, 2,…, n.

2.3. The weight of index

Based on the importance of the index to the upper level's index about a rule, we can get the weight of this index. When the weights of all indexes at the same level, the weight set can be got that is A= (a_1, a_2, a_3, a_4, a_5). The AHP is used to get the weight of index with hierarchical structure model.

(1) The comparison matrix

In order to get the importance to the upper level's index, we can compare the index i and j at the same level. And the importance should be assigned by deciders and experts. By the method of AHP, the estimate about importance of an index should be quantified with some ratio scale. The 1-9 scale method is employed by this paper. If there are n indexes at this level, the comparison matrix is C= (C_{ij}) and C_{ij} is the assignment about importance of the index i to j.

(2) Weight calculation

The weight computing problem is how to get the maximized eigenvalue and eigenvector of comparison matrix.

Calculating each row comparison matrix elements' product Mi.

$$M_i = \prod_{j}^{n} a_{ij}, \quad i = 1,2,\cdots n \tag{1}$$

Calculating Nth root Wi of product Mi

$$\overline{W_i} = \sqrt[n]{M_i} \tag{2}$$

Normalized vector $\overline{W} = \left[\overline{W_1}, \overline{W_2}, \cdots \overline{W_n}\right]^T$

$$W_i = \frac{\overline{W_i}}{\sum_{j=1}^{n} \overline{W_j}} \tag{3}$$

$W = \left[W_1, W_2, \cdots W_n\right]^T$ is the eigenvector.

Calculating the maximized eigenvalue of comparison matrix.

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} \tag{4}$$

(3) The consistency of comparison matrix

Although comparison matrix makes critical thinking mathematical, the consistency of comparison matrix and critical thinking should be tested. When the importance of indexes is estimated by experts, the result of estimate by different experts must be consistency. So when the AHP is employed, the consistency of comparison matrix should be tested to ensure the consistency of critical thinking provided by different experts. We can use consistency ratio *C.R.* to test the consistency of comparison matrix.

$$C.R. = \frac{C.I.}{R.I.} \tag{5}$$

C.I. is consistency index and $C.I. \frac{\lambda_{\max} - n}{n-1}$; R.I. is random index and the value of *R.I.* can be got with table 1.

Table 1. Values of *R.I.*

Dimension	3	4	5	6	7	8	9
R.I.	0.5149	0.8931	1.1185	1.2494	1.3450	1.4200	1.4616

If *C.R.* <0.1, the comparison matrix is accepted.

2.4. Membership functions and fuzzy evaluation matrix

The role of membership functions is to get the safety evaluation grade of warning monitoring index. The form of membership functions is plentiful. So we should select a suitable membership functions according to the character of warning monitoring index and the experience of the experts. The generalized bell function is employed by this paper.

$$f(x,a,b,c)=\frac{1}{1+\left|\frac{x-c}{a}\right|^{2b}} \tag{6}$$

The parameters of function are a, b and c. The value of a is 5 and b, 4. Correspond to very safe, safe, common, risky and very risky, the value of c is 97.5, 87.5, 77.5, 67.5 and 57.5.

If the membership of a warning monitoring index u_i to the safety evaluation grade v_j is r_{ij}, we can get the fuzzy evaluation matrix R.

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \tag{7}$$

2.5. Fuzzy Comprehensive Evaluation

According to the AHP, the process of comprehensive evaluation is from the lower level of hierarchical structure model to the high level. By use of the weight set A of indexes and the fuzzy evaluation matrix R, the fuzzy comprehensive evaluation vector B can be got.

$$B = A \cdot R = (b_1, b_2, \cdots, b_m) \tag{8}$$

The fuzzy comprehensive evaluation index b_j is the membership of evaluation objects to evaluation grade v_j.

2.6. Integrated evaluation and safety class

By defuzzification of the fuzzy comprehensive evaluation index b_j, the final evaluation results can be got. A lot of methods can be employed to achieve defuzzification and the weighted average method is employed by this paper.

Combine weighting vector and fuzzy comprehensive evaluation vector, the integrated evaluation can be got.

$$Z = \gamma \cdot B^T \tag{9}$$

By consulting the warning standards of integrated evaluation, we can determine the safety class.

3. Example

Based on 5 year data from produce locale, the safety early warning model of a coal mine belong to Huangling Group is created and tested.

3.1. Evaluation grade set and warning monitoring index set

The evaluation grade set is $V=\{v_1,v_2,v_3,v_4,v_5\}$={very safe, safe, common, risky, very risky} and the warning monitoring index set is $U=\{U_i\}$, i=1~5, $U_i=\{U_{ij}\}$, j=1~n.

3.2. The weight of index of coal mine

Based on actual situation of the coal mine and experts ' advice, the comparison matrix is got by 1-9 scale method. For example, the comparison matrix of working condition index is provided in Table 2.

Table 2. Comparison matrix of working condition indexes

U_4	U_{41}	U_{42}	U_{43}	U_{44}	U_{45}	U_{46}	U_{47}	M_j	w	W_j
U_{41}	1	2	3	6	4	8	7	8064	3.61	0.35
U_{42}	1/2	1	2	5	3	7	6	630	2.52	0.25
U_{43}	1/3	1/2	1	4	2	6	5	40	1.69	0.17
U_{44}	1/6	1/5	1/4	1	1/3	3	2	0.0167	0.56	0.05
U_{45}	1/4	1/3	1/2	3	1	5	4	2.5000	1.14	0.11
U_{46}	1/8	1/7	1/6	1/3	1/5	1	1/2	0.0001	0.27	0.03
U_{47}	1/7	1/6	1/5	1/2	1/4	2	1	0.0012	0.38	0.04
	λ_{max}=7.249,*CI*=0.036,*RI*=1.32,*CR*=0.027<0.10								10.17	1.00

As fellows, we can get the weight of the 2nd level index.

A_1= (0.2655 0.2655 0.1770 0.1192 0.0413 0.0813 0.0210 0.0291);

A_2= (0.1952 0.1136 0.0497 0.3208 0.3208);

A_3= (0.1825 0.1825 0.1239 0.2611 0.0853 0.0289 0.0590 0.0410 0.0153 0.0207)

A_4= (0.3555 0.2470 0.1666 0.0548 0.1121 0.0264 0.0376)

A_5= (0.2000 0.2000 0.6000)

The weight of the 1st level index is A= (0.0584 0.4200 0.1708 0.1064 0.2444).

3.3. The fuzzy evaluation matrix of coal mine

According to the monitoring indexes system, every index about working condition, for instance, should be acquired from field. For example, the monitoring indexes of working condition are listed below. The average wind speed is 2.46; the supply-demand ratio of air flow is 1.08; the minimum pedestrian elevation of mine workings is 1.62; the minimum pedestrian width of mine workings is 1.08; the temperature is 22.2; the dust concentration is 4.89; the qualification rate of mine workings is 92.6. Then the fuzzy evaluation matrix of working condition can be got by using the method above.

$$\boldsymbol{R}_4 = \begin{bmatrix} 0.9652 & 0.0878 & 0.0001 & 0 & 0 \\ 0.0004 & 0 & 0 & 0 & 0 \\ 0.0013 & 0.9999 & 0.0141 & 0 & 0 \\ 0.0001 & 0.0635 & 0.9835 & 0.0005 & 0 \\ 0.067 & 0.9812 & 0.0005 & 0 & 0 \\ 0.067 & 0.9812 & 0.0005 & 0 & 0 \\ 0.5403 & 0.4605 & 0.0001 & 0 & 0 \end{bmatrix}$$

When all fuzzy evaluation matrixes of the 2nd level indexes are got, we can get the fuzzy evaluation matrixes of the 1st level index.

$$\boldsymbol{R} = \begin{bmatrix} 0.021 & 0.2655 & 0.0413 & 0.0021 & 0 \\ 0.0059 & 0.3208 & 0.0376 & 0 & 0 \\ 0.1825 & 0.2611 & 0.0059 & 0 & 0 \\ 0.3555 & 0.1666 & 0.0548 & 0.0005 & 0 \\ 0.1092 & 0.6 & 0.0026 & 0 & 0 \end{bmatrix}$$

3.4. The safety class of coal mine

Combine the weight and fuzzy evaluation matrix with formula 8, the fuzzy evaluation vector B can be got. First, we can figure out the 2nd level fuzzy evaluation vector.

To U_1 (geological environment): B_1=(0.021 0.2655 0.0413 0.0413 0.0021);

To U_2 (human): B_2=(0.0059 0.3208 0.0376 0 0);

To U_3 (equipment): B_3=(0.1825 0.2615 0.0059 0 0);

To U_4 (working condition): B_4=(0.3555 0.1666 0.0548 0.0005 0);

To U_5 (management): B_5= (0.1092 0.6000 0.0026 0 0)

Then the 1st level fuzzy evaluation vector is got.

To U (warning monitoring index): B= (0.1708 0.2444 0.0548 0.0005 0)

The safety class of coal mine is divided into 5 grades. To the safe grade of very safe, safe, common, risky and very risky, the relevant weighting vector is γ= (0.95, 0.85, 0.75, 0.65, 0.55). The warning standards of integrated evaluation should be determined in advance. In this paper, To the safe grade of very safe, safe, common, risky and very risky, the warning standards of integrated evaluation are [1,0.9], (0.9,0.8], (0.8,0.7], (0.7,0.6], (0.6,0]. After fuzzy evaluation vectors are normalized, the integrated evaluations can be got with formula 9.

Z1=0.821, Z2=0.841, Z3=0.902, Z4=0.889, Z5=0.865, Z=0.855.

According to the result, geological environment, human, equipment and management are “safe” and working condition is “very safe” and the whole system of the coal mine is “safe”.

4. Conclusion

The safety issue of coal mining engineering is very important to coal industry. According to the coal mine enterprises' safe characteristics, this paper introduced early warning mechanism to the safety management of coal mine. By using the fuzzy AHP method, the index system about coal mine safety and the safety early warning model of coal mining engineering are established.

According to our coal mine enterprises' safe characteristics, this paper analyzed the risk factors of coal mining engineering and studied the safety problem of “human-machine-environment” system. The risk factors of coal mining engineering are divided to natural geological factors, personnel factors, equipment factors and management factors. Based on the fuzzy mathematics and these factors, the safety early warning model of coal mining engineering is constructed by using the fuzzy AHP method. Combined with the production mine of Huangling Group, this early warning model is applied to the mining operations process. The results show that this early warning model is effective to prevent the accident.

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